THUNDERSTORMS: ESPECIALLY THOSE OF OHIO.*

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I. Thunderstorms in General.

1. *Introduction*

The typical thunderstorm, that is, the thunderstorm complete in every detail from its beginning to its ending, has ever held a unique place in the world of human thought and speculation as evidenced by its large and conspicuous place in ancient mythology, by its scarcely less conspicuous place in the history and literature of the race, and by the earnest consideration it has received from the brightest minds of the scientific age. Not only so, but its physical characteristics are such as to assure it a place of real and permanent interest in our present and future thinking along meteorological lines.

We are told upon apparently good authority[1]† that more myths have gathered about the thunderstorm and its phenomena than about any other natural phenomenon, except possibly light and darkness. And we are quite prepared to believe it when we recall the ominous stillness of the air, the darkness of the sky, the lurid glare of the clouds, the majestic roar of the thunder, and the indescribable effects of the highly electrified bodies on the nerves of many people. If these storms inspire so much awe in the human mind in a scientific age—in these days of our boasted intellectual emancipation—with what unspeakable awe must the primitive mind have regarded them! No wonder the thunderstorm was looked upon as a mystery that pressed for solution or explanation. These early "explanations" have come down to us as myths, which, like most myths, are of interest to us chiefly because they constitute the first efforts of the human mind to explain natural phenomena. Then, as now, a thing was regarded as *explained* when classified with other things with which we are acquainted.

*Presidential address, delivered at the Cleveland meeting of the Ohio Academy of Science.

†For numbers of reference, consult bibliography at close of paper.

We explain, for example, the origin, the progress and the ending of a thunderstorm when we classify the phenomena presented by it with other more familiar phenomena of vaporization and condensation. But primitive man explained the same thing, to his own satisfaction at least, when he classified it along with the well-known phenomena of human volition by constructing a theory of a great black dragon pierced by the unerring arrows of an heavenly archer. As late as 1600, a German writer would illustrate a thunderstorm destroying a crop of corn by the picture of a dragon devouring the produce of the field with his flaming tongue and iron teeth. But we of today no longer regard the thunderstorm as an object of terror or as an unfathomable mystery, but rather as a natural phenomenon of great economic and scientific interest, one in every way worthy of our best and most serious consideration.

The physics and physical features of the thunderstorm are, we believe, fairly well understood. These have been ably and fully discussed by Professor Humphreys of the U. S. Weather Bureau, whose teaching we follow very closely in this discussion. If the thunderstorm produced *only* lightning and thunder, it would be of only relative importance, but it may bring along a whole series of redoubtable phenomena, thus presenting problems of real practical importance—problems the magnitude and importance of which are not always fully appreciated.

2. Definition

And now, first of all, let us ask and answer, if we can, this question: "What is a thunderstorm?" Ordinarily, for example, we think of a windstorm as a storm characterized by high and perhaps destructive *winds;* of a hailstorm as one characterized by the production of *hail;* of a snowstorm as one that produces *snow;* of a dust storm as one characterized by a great quantity of flying *dust;* and so, quite properly, we think of a thunderstorm as a storm characterized by *thunder* and lightning. This may not, I grant you, serve as a satisfactory *definition*, but it will, perhaps, be a sufficient *answer* for the time being to the question asked.

It is not necessary in this presence, perhaps, to point out that the "snow," the "wind," the "hail," and the "dust," are in no sense the *cause* of the storm to which they give name.

Nor, so far as known, have the lightning and thunder any influence on the formation, progress and termination of the thunder-storm, although they may and often do constitute the most impressive, spectacular, and even tragic features of the storm. For as Prof. Humphreys well says,[2] "No matter how impressive or how terrifying these phenomena may be, they never are anything more than mere incidents to or products of the peculiar storms they accompany. In short, they are never in any sense either storm-originating or storm-controlling factors."

3. Source of the Lightning

Since we cannot have a thunderstorm without thunder, and cannot have thunder without *lightning*, it seems quite essential to a proper understanding of these storms to get a correct, scientific explanation of the source or cause of the lightning. Oh, yes, we are fully aware of the danger just here—namely, how easily and how quickly one may get beyond his depth when talking about the origin of electricity. We must admit, of course, that we know very little if anything for certain at this point, but then we would like to *appear* to know something about this interesting phase of our discussion. We are deeply indebted to Dr. G. C. Simpson[3] of the Indian Meteorological Department for our best information or knowledge on this point. Dr. Simpson, by numerous observations and laboratory experiments found out a great many extremely valuable things concerning the electricity brought down by the raindrop and the snowflake, and at the same time, by means of a number of well-devised experiments, determined the electrical effects of each obvious process that takes place in the thunderstorm. He found out, for example, that no electrification resulted from freezing and thawing, air-friction, etc., but that when he allowed drops of *distilled water* to fall through a vertical blast of air of sufficient strength to produce some spray,

(1) That breaking of drops of water is accompanied by the production of both positive and negative ions.

(2) That three times as many negative ions as positive ions are released.

"Now," as pointed out by Professor Humphreys[2], "a strong upward current of air is one of the most conspicuous features of the thunderstorm. It is always evident in the turbulent cauliflower heads of the cumulus cloud, the parent, presumably, of all thunderstorm. Besides, its inference is compelled by the occurrence of hail, a frequent thunderstorm phenomenon, whose formation requires the carrying of raindrops and the growing hailstones repeatedly to cold and therefore high altitudes. And from the existence of hail it is further inferred that an updraft of at least eight meters per second must often occur within the body of the storm, since, as experiment shows, it requires approximately this velocity to support the larger drops, and even a greater velocity to support the average hailstone.

"Experiment also shows that rain can not fall through air of ordinary density whose upward velocity is greater than about eight meters per second, or itself fall with greater velocity through still air; that in such a current, or with such a velocity, drops large enough, if kept in tact, to force their way down, or, through the action of gravity, to attain a greater velocity than eight meters per second with reference to the air, whether still or in motion, are so blown to pieces that the increased ratio of supporting area to total mass causes the resulting spray to be carried aloft or left behind, together with, of course, all original smaller drops. Clearly, then, the updrafts within a cumulus cloud frequently must break up at about the same level innumerable drops which, through coalescence, have grown beyond the critical size, and thereby according to Simpson's experiments, produce electrical separation within the cloud itself. Obviously, under the turmoil of a thunderstorm, its choppy surges and pulses, such drops may be forced through the cycle of union (facilitated by any charges they may carry) and division, of coalescence and disruption, from one to many times, with the formation on each at every disruption, again *according to experiment*, of a correspondingly increased electrical charge. The turmoil compels mechanical contact between the drops, whereupon the charges break down the surface tension and insure coalescence. Hence, once started, the electricity of a thunderstorm rapidly grows to a considerable maximum.

"After a time the larger drops reach, here and there, places below which the up-draft is small—the air can not be rushing up everywhere—and then fall as positively charged rain, because of the processes just explained. The negative electrons in the meantime are carried up into the higher portions of the cumulus, where they unite with the cloud particles and thereby facilitate their coalescence into negatively charged drops. Hence, the heavy rain of a thunderstorm should be positively charged, as it almost always is, and the gentler portions negatively charged which very frequently is the case.

"Such in brief, is Dr. Simpson's theory of the origin of the electricity in thunderstorms, a theory that fully accounts for the facts of observation and in turn is itself abundantly supported by laboratory tests and simulative experiments.

"If this theory is correct, and it seems well founded, it must follow that the *one essential* to the formation of the giant cumulus cloud, namely, *the rapid uprush of moist air*, is also the one essential to the generation of the electricity of thunderstorms. Hence the reason why lightning seldom if ever occurs except in connection with a cumulus cloud is understandable and obvious. It is simply because the only process that can produce the one is also the process that is necessary and sufficient for the production of the other."

4. Turbulence of the Cumulus Cloud.

That the large cumulus clouds, especially those that produce thunderstorms, are exceedingly turbulent within with violent vertical motion, as demanded by the theory just outlined, is evident to even the casual observer. Furthermore the testimony of those balloonists who have had the trying ordeal of passing through the heart of a thunderstorm confirms the facts of observation. Since these are the only clouds, apparently, characterized by this high degree of turbulence, it may be well to pause a moment and ask why these motions—motions which, in the magnitude of their vertical components and degree of turmoil, are never exhibited by clouds of any other kind nor are they met with elsewhere by either manned, sounding or pilot balloons. Without going into very great detail, it may be pointed out, as has been done by von Bezold[4], that the heat liberated by the sudden condensation from a state of supersaturation, and also from the sudden congelation of undercooled cloud particles, would cause an equally sudden expansion of the atmosphere, resulting in turbulent motions analogous to those observed in the large cumulus clouds.

This, however, is not sufficient to account for all the observed facts, since it is not clear just how either the condensation or the congelation could suddenly take place throughout a cloud volume great enough to produce the observed effects. We must, therefore, look for some other explanation, and this we shall probably find, *in the difference between the actual temperature gradient of the surrounding atmosphere and the adiabatic temperature gradient of the saturated air within the cloud itself;* or, in other words, the cause of the violent up-rush and turbulent condition within large cumulus clouds is, presumably, the difference between the temperature of the inner or warmer portions of the cloud itself and that of the surrounding atmosphere at the same level.

5. *Causes of Convectional Instability.*

As we have just tried to show the *sine qui non* of the thunderstorm is the *rapid* vertical convection of *moist air;* the up-rush must be *rapid* and the air must be *moist;* one without the other is not sufficient. We may have, for example, a *very* rapid convection over a desert region but there being no moisture there will be no cloud-formation and therefore no thunderstorm. On the other hand we may have air ever so humid but if the movement upward is too gentle not even a cloud may result, but if a cloud, certainly no thunderstorm. It is obvious, therefore, that we must have both "rapid convection" and "moist air."

This leads us to a consideration of the conditions under which the vertical temperature gradients necessary to this convection can be established. These conditions are, according to Prof. Humphreys, three in number, namely:

(1) A strong surface heating, expecially in regions of light winds.
(2) The over-running of one layer of air by another at a temperature sufficiently lower to induce convection.
(3) The under-running and consequent uplift of a saturated layer of air by a denser layer.

Of these three conditions, the first mentioned—"strong heating surfaces"—is, for obvious reasons, of most frequent occurrence over the land surfaces of the earth; number two is also of frequent occurrence on land and is, perhaps, well nigh the sole cause of thunderstorms on the ocean. Number three is by far less frequently the cause of thunderstorms than the other two, for while the actual *under-running* is of rather frequent occurrence, it seems probable that only occasionally is the uplift of sufficient magnitude to cause a thunderstorm.

6. *Periodic Recurrence of Thunderstorms.*

Keeping in mind the conditions or factors absolutely essential to the formation of a thunderstorm, we are well prepared to consider, perhaps in a measure to anticipate, the periodic recurrence and distribution of thunderstorms, for while it is possible, of course, for a thunderstorm to occur on any day at any hour, yet the fact is, and for obvious reasons, the day has its period of maximum thunderstorm activity, the year its maximum period, and there is some evidence of irregular cyclic periods of maximum activity, each maximum depending upon the simple facts that the more humid the air and the more rapid the local vertical convections the more frequent and also the more intense the thunderstorms.

Taking the *day* as our unit, we find the period of maximum thunderstorm activity is not the same over the land as over the ocean. Vertical convection of the atmosphere over the land is most pronounced, of course, when the surfaces are most heated, namely, in the afternoons; hence the inland or continental thunderstorm occurs most frequently, in most places, between 2 and 4 P. M. Over the ocean, however, the temper ature gradients that are most favorable for rapid vertical convection are most frequent during the early morning hours, and therefore thunderstorms usually occur on the ocean between midnight and 4 A. M. If we take the *year* as our unit, we find, for reasons that will readily occur to all, that thunderstorms are most frequent, over the land, when the surface heating is at a maximum, in middle latitudes in June and in the higher latitudes in July or August. Over the ocean, however, the thunderstorm is most frequent in the winter months.

Furthermore, since the thunderstorm is vitally associated with rainfall and high temperature, it must follow that a *cycle* of warm, wet years would give a maximum of thunderstorms and a cycle of cold, dry years a minimum.

We have the key to the *geographical* distribution of thunderstorms in the conditions essential to their production, and while it is safe to say that the thunderstorm, in one form or another, does occur at some time or other in all parts of the earth, yet from what we know of the meteorological conditions ordinarily prevailing over the various portions of the earth, we are very sure that it is very rare over large areas and may never occur in some regions. In the United States[5], for example, we find two centers of maximum thunderstorm activity, one over Tampa, Florida, and the other over Santa Fe, New Mexico. In the ten-year period, 1904-1913, 944 thunderstorms were recorded at Tampa and 710 at Santa Fe. Tampa is near sea-level and Santa Fe is about 7,000 feet above the sêa.

7. *Classification of Thunderstorms.*

One is impressed with the very great variety and many variations met with in the study of these storms. This is true whether one is considering the attendant circumstances, the varying degree of intensity exhibited by them, the frequency of occurrence, the resulting effects, the distribution through the day, the year, or over the earth's surface, or whether one is considering the factors operating to produce and maintain these storms. Variety everywhere!

At one time, and not so long ago, it was thought that all thunderstorms were local phenomena and were therefore not subject to any general law. In an important sense the thunderstorm is a local phenomenon but the forces operating to produce many of them are far from local. It is now known that a majority of these storms travel in a definite direction and are therefore moving under a general law. In general, with respect to the producing causes or conditions out of which they grow, thunderstorms may be divided into (1) local or "heat" thunderstorms, and (2) the cyclonic thunderstorms, or "thundersqualls." Or, if we wish to be a little more exact or "scientific," we may follow Professor Humphreys and make five classes, namely, (1) the "heat" or local, (2) the cyclonic, (3) the tornadic, (4) the anti-cylconic, and (5) the "border," thunderstorm. The significance of this classification will be pointed out later in connection with the illustrated portion of this lecture but it seems appropriate at this time to refer to Durand-Greville's famous theory of "the squall zone" in connection with cyclonic thunderstorms. He holds that "cyclonic thunderstorms"—and that means all except the "local" or "heat" thunderstorm—are but an accessory result of a body of extremely complex phenomena—an organism someone has called it[6]—the *squall*, which is subject to fixed laws and forms an integral part of certain lows. This so-called "squall zone" in which, according to Durand-Greville[7], nearly all "cyclonic" thunderstorms, or as he calls them, "thundersqualls," occur, starts some where near the center of the barometric depression or "low" and usually extends out to its boundary, thus having a length of a thousand miles or more, while its width may vary from 10 to 60 miles or more. This zone moves, advances or recedes, with the "low" of which it is a part, as a rule remaining parallel with itself. Should the "low" remain stationary, the squall zone may, and usually does, swing round the center. The passage of the "squall zone" over any given place, shown by the familiar "squall hook" of the barograph trace, is attended by the concomitant production of certain phenomena that occur only within the limits of the zone. They begin at the moment the "squall front" of the squall zone reaches the place of observation, they rapidly attain their maximum intensity, and then gradually weaken and finally die out as the rear of the zone passes and normal conditions become established. These accompanying phenomena may be more or less numerous, thus giving rise to a variety of "squalls," each characterized by its appropriate phenomena. These squalls have been classified by Durand-Greville as follows, viz.:

Durand-Greville's Classification of Squalls[8]

<table>
<tr><td>1. Sudden increase in wind velocity</td><td rowspan="3">White squall</td><td rowspan="6">Wind squall</td><td rowspan="7">Rain, hail, or snow squall</td><td rowspan="8">Thunder squall</td></tr>
<tr><td>2. Sudden change in wind direction</td></tr>
<tr><td>3. Sudden rise in pressure</td></tr>
<tr><td>4. Sudden fall in pressure</td></tr>
<tr><td>5. Sudden rise in relative humidity</td></tr>
<tr><td>6. Rapid increase in cloudiness</td></tr>
<tr><td>7. Downpours of
rain
hail
snow</td></tr>
<tr><td>8. Lightning and thunder</td></tr>
</table>

The basis of this classification is, as you see, increasing complexity. Note also that the phenomena observed during the passage of a squall are actually the results of two causes, one of these, the "squall wind," is purely *dynamic*, pre-existant, and may be of distant origin; the other is the local condition of the atmosphere and is *static*.

8. The Mechanism of the Thunderstorm.

Thus far we have considered the thunderstorm in a more or less general way—its definition, its causes, its recurrence, its distribution, its relation to areas of high and low pressure, etc. Let us now consider *a* typical thunderstorm in actual progress and note its mechanism and some of its more important phenomena. Just here the slide would be very helpful but we shall content ourselves just now with the bare mention of some of the things that one may look for in the well-defined thunderstorm. Among these may be mentioned the winds, the squall cloud, the pressure, the temperature, the humidity, the rain, the hail, the so-called "rain-gush," the rate of advance of the storm, the lightning, and the thunder.

First, the thunderstorm winds must be carefully considered if one is to understand fully the mechanism of the thunderstorm itself. As every one knows, as a thunderstorm approaches a given place the wind at that place is generally light and from a direction that carries it across the path of the approaching storm, that just before the rain begins the wind begins to die down, almost to a calm, and to change its direction. When this change is complete it blows for a few moments, rather gently, directly toward the nearest portion of the storm front, and finally as the rain is almost at hand, there is a sudden change of direction and the wind now comes, often in violent gusts, directly away from the storm and in the direction the storm is moving, a direction quite different from the original direction of the wind. As a rule these strong gusts of wind last through the early part of the storm only and then follow gentle winds again, at first following the storm but after an hour or so they blow from the same general direction as the original surface winds. Now, as we have tried to show, the thunderstorm is the child of a cumulus cloud and the cumulus cloud is the child of a vertical convection which results from a more or less super-adiabatic temperature gradient. This gradient may be established in one of three ways, as above pointed out. Now, inasmuch as the passage of a cumulus cloud overhead, however large, so long as rain does not fall from it, does not materially disturb the surface winds, in other words, does not bring on any of the familiar gusts and other thunderstorm phenomena, we must infer that in some way the rain is an important factor both in starting and maintaining the winds we have just noted. On the other hand we cannot assume that the rain is the whole cause of these winds for they do not accompany other and ordinary showers, however heavy the rainfall.

The "rain-gush" or heavy downpour after a heavy clap of thunder has often been misunderstood and has been made to serve as a proof of the claims of the so-called "rain-makers." The fact is the rain is the cause of the thunder or lightning, and not the thunder the cause of the heavy rain.

Then there is the *lightning* in its various forms, the "streak" lightning, the so-called "rocker" lightning, the "ball" lightning, the "sheet" lightning, the "beaded" (?) lightning, the "return" lightning, and some people say the "dark" lightning, and so on. To discuss all these would carry us far beyond our limit. Then there is the question of the temperature along the path of a lightning discharge, how does the lightning render the atmosphere through which it passes luminous, etc. Perhaps no one knows the answer to these questions but it is very certain that the temperature along the path of the lightning discharge is very high from the fact that it sets fire to many objects, such as buildings, that fall within its path. Just how the lightning discharge renders its path through the atmosphere luminous is not definitely known. Of course it does make the air along its path very hot but no one so far as I know has ever succeeded by any ordinary means in rendering oxygen or nitrogen luminous by heating. It must be therefore, that the luminosity is due to something besides high temperature, probably, according to Prof. Humphreys, to "internal atomic disturbances induced by the swiftly moving electrons of the discharge." The spectrum reveals to us the interesting fact that lightning flashes are of two colors, white and pink or rose. The rose-colored flashes, when examined in the spectroscope, show several lines due to hydrogen, which of course are due to the decomposition of some of the water along the lightning path. The duration of the lightning discharge is exceedingly variable, ranging from 0.0002 second for a single flash to, in rare cases, even a full second or more for a multiple flash consisting of a primary and a series of subsequent flashes. The lightning discharge is direct, not alternating, as shown by the fact that the lightning may operate telegraph instruments, may reverse the polarity of dynamos, both of which requires a direct current.

The length of the lightning streak also varies greatly. When the discharge is from cloud to earth the length is seldom more than 2 or 3 kilometers, but when from cloud to cloud may be 10 to 20 kilometers (6 to 12 miles). The path of the lightning discharge may extend from the cloud to earth, from one portion to another of the same cloud, or from one cloud to another cloud. Obviously the second case is of the most frequent occurrence, that is, from the upper to the lower portion of the same cloud; from cloud to earth is next in point of frequency, and from cloud to cloud, relatively rare. Sometimes the discharge from cloud to earth may include in its strange and tortuous path objects that have not sufficient conductivity to carry it and as a result of the sudden and excessive heating many very freakish things may be done, such as shingles blown off, chimneys shattered, trees stripped of their bark or splintered, wires fused, even holes melted through metal, etc. Then there are certain chemical reactions resulting from these electrical discharges that play an important part in the economy of nature. For instance the health-giving ozone of the atmosphere is greatly increased by the passage of a thunderstorm, and even the fertility of the soil may be increased by the production of considerable quantities of ammonia and soluble salts.

Perhaps, a word or two should be said regarding the *danger* to life incident to the passage of a thunderstorm. That there is danger, even great danger at times, is abundantly shown from the tragic statistics of deaths each year from this cause. While it is not possible, perhaps, to remove this danger, it is possible to reduce it, chiefly by avoiding the points of greatest danger. In general, it is safer inside than outside of a house, especially if the house has a well-grounded rod or metal roof; it is also safer in the valley than on a hill or elevated portion of land, this because the chance for a cloud-to-earth discharge varies inversely as the distance between them; it is also very unsafe to take refuge under a tree and the taller the tree the greater the danger. No tree is immune but those trees having an extensive root system or a deep tap-root are most apt to be struck because they are the best grounded and therefore offer the least electrical resistance. Then again if one is caught out of doors and is exposed to a violent thunderstorm it is best so far as danger from lightning is concerned, to let one's clothes get soaking wet, because wet clothes are much better conductors and dry clothes much poorer conductors, than the human body. It might even be advisable to lie flat on the wet ground, undignified as this may be. For any given locality, the lower the cloud the greater the danger; hence, when the humidity is high it is favorable for a dangerous storm, since the cloud will form at a low level and the rain is apt to be very abundant. For the same reason a winter storm is likely to be more dangerous than a summer storm of equal intensity.

And now how do we account for the *thunder*—that particular feature that gives name to our storm? It has taken quite a while to answer this question satisfactorily. Many very silly theories still persist. The electrical discharge, the "lightning," furnishes the key to the explanation. The sudden and intense heating of the air along the path of the discharge causes it to expand suddenly and violently, sending out from every part of its path a steep compression wave, which, as we understand it, is the real cause of the thunder. The "rumbling" that sometimes follows is due, chiefly perhaps, to the inequality in the distances from the observer to the various portions of the lightning's path, to the crookedness of the path, to a succession of discharges, and to some extent to reflection under favorable conditions. The distance to which thunder may be heard varies from 7 to 15 miles.

9. *Forecasting the Thunderstorm.*

The forecasting of conditions favorable for the formation of thunderstorms one or two days in advance is comparatively easy but to say, even a few hours in advance, that a thunderstorm will occur at a given place, at or about a given time, is, to say the least, a hazardous venture. It is only after the storm has actually begun and its direction and rate of movement have been determined, can one speak with even a small degree of assurance. As every one knows, a storm may occur, in fact several of them, in sight of the observer and yet not at the place of observation. Then besides the thunderstorm is of a very limited duration; it may, at the very most, last twenty-four hours, but as a rule a very few hours will exhaust it. It is only when this type of storm assumes the character of a tornado that knowledge of its approach becomes really important.

10. The Thunderstorm and Excessive Precipitation.

Another thing that gives to the thunderstorm economic importance is the fact that from 66 to 100 per cent of all instances of excessive precipitation in the United States occur as the result of or in connection with thunderstorms[9]. Some places, like Bismark, Denver and Sante Fe, excessive precipitation never occurs except in connection with thunderstorms. Furthermore, the records will show that practically all cases of remarkable downpours of rain or hail occur in connection with these storms.

II. Thunderstorms in Ohio.

1. Introduction.

Needless to say, the thunderstorms of Ohio do not differ in any essential respect from those we have been discussing. Our chief and perhaps only excuse for referring to them at this time and in this manner is to make an occasion to call the attention of the Academy to a piece of work accomplished in Ohio that, so far as we know, is the only one of its kind in this or any other country, namely an intensive study of thunderstorms over a limited region through a period of one year. The purposes were to determine as far as practicable the origin, the distribution, the number, the frequency, the extent of territory covered, the attending phenomena, etc., of these storms, and if possible, trace the history of each individual thunderstorm that entered or originated in the state of Ohio, during the year 1917.

2. The Plan.

Our plan was to secure at least one observer in each township in the State but as the work was to be purely gratuitous we were not able to interest one person in each of the 1357 townships. Our total enlistment was about 730 volunteer observers, about 130 co-operative observers and the six regular Weather Bureau stations in the State. We also received some assistance from the telephone and telegraph companies in the State and even dealers in lightning rods.

3. Forms and Instruction.

Each observer was then supplied with full instructions and a suitable card on which to make his report of each storm. This form called for the exact date and time of the storm, the exact location of the observer, time first, loudest and last thunder was heard, direction the storm moved, time rain began and ended, time hail began and ended, direction of wind before and after the storm, etc. The weakness of the plan was, of course, in the fact that it was dependent upon voluntary service and as was to have been expected, some observers failed us at the critical moment, so that we were not always sure we had the complete history of each storm. However, we assembled quite a mass of thunderstorm data and these have been charted and otherwise prepared for publication.

3. A Resume.

Among the many interesting facts brought out in the special study of thunderstorms in Ohio during the year 1917, may be mentioned, briefly, the following:

(a) Thunderstorms in Ohio are incident to the *passage* of those cyclonic areas (see M. W. R., Supplement No. 1) that move directly over or just north of the State, and to the *approach* of those that move just south of the State. The first group includes the Alberta, the North Pacific, the Rocky Mountain and probably the Central and Colorado types; the second group includes the South Pacific and the Texas types, especially those that follow a northeasterly course.

The passage of the Alberta type, especially in the late winter or early spring months, will cause thunderstorms in Ohio when the wind-shift line, or "squall line," is pronounced, and extends in a north-south, or a northeast-southwest direction. These thunderstorms will set in slightly in advance of this line and will continue until it has passed. See weather map of January 31, 1917, 7 A. M. The passage of the North Pacific, the Northern Rocky Mountain, the Central, and the Colorado types, will cause thunderstorms in Ohio only when an area of high pressure prevails over the eastern Lake Region or New England. See weather map of April 17, 1917, 7 A. M. As these types are usually followed by a high pressure area from the northwest of more or less intensity and therefore move with considerable rapidity, the thunderstorms incident thereto are apt to be of short duration and are seldom of a violent character.

But to the approach of the South Pacific and Texas types is to be attributed by far the greater portion of the thunderstorms in Ohio. These types prevail from early May into late October. As a rule thunderstorms will set in over the western part of the State when the center of the "low" reaches Missouri or southern Illinois and will probably become general over the State. These cyclonic types often bring thunderstorms of a very violent nature. When the "low" passes over the northwestern corner of the State, thus forcing the isotherms far northward of their normal position, and is followed by a "high" of moderate intensity, hailstorms are likely to occur with the shift of the wind—passage of the squall line—and subsequent increase in pressure. See weather maps of March 10 and 11, 1917. The position of the Atlantic high does not seem to have any material effect on the rain-producing characteristics of these "lows." When the path of these cyclonic types suddenly curves to the north and passes into the Lake Region from northern Indiana or Illinois, thunderstorms are likely to occur in Ohio both on the approach and the passage of these areas. Normally, however, their passage just over or just south of the State is followed by brisk westerly winds, clearing weather and falling temperature.

The East Gulf and South Atlantic types gave rise to no thunderstorms in Ohio during the year 1917.

(b) The data seem to show certain centers of maximum activity and storm-frequency. The southwestern part of the State is certainly the most favorable portion for the development of the tornado as all tornadoes of consequence in the history of the Bureau have occurred in that section.

(c) Thunderstorms were reported on 169 days, midnight to midnight. Of these 169 days, thunderstorms occurred in the forenoon only on 22 days, on the afternoon only on 80 days, on both forenoon and afternoon on 63 days, on 9 days the storm began in the forenoon and ended in the afternoon, and on 2 occasions the storm began on the afternoon or evening of one day and ended in the early morning of the following day. Note that the afternoon thunderstorm is about four times as frequent as the forenoon, that the number of days with thunderstorms both morning and afternoon is quite large, that the number of days on which the storm begins in the forenoon and continues into the afternoon is quite small and the number beginning in the afternoon or evening and continuing beyond midnight is smaller still.

The reports further show that at leats 31 persons were killed during the year by lightning, 70 others more or less injured; in addition, a large number of animals were killed and much property destroyed. We have no reliable figures as to how many times the lightning actually struck but we learn from the report of the State Fire Marshal that 215 fires were started during the year as the result of a lightning stroke, destroying property valued at about $370,000. The 215 objects damaged or destroyed were classified as follows: 137 barns, 53 dwellings, 4 churches, 4 sheds, 4 warehouses, 2 haystacks, 2 oil tanks, 1 dry cleaning establishment, 1 hotel, 1 livery stable, 1 school house, 1 straw stack, 1 manufacturing establishment and 2 mercantile buildings. The Fire Marshal's office takes no note of lightning strokes that do not start a fire or cause the loss of human life. These fires were distributed through the months as follows, viz.: February, 5; March, 6; April, 5; May, 33; June, 27; July, 45; August, 66; September, 17; October, 11; January, November and December, *none.*

Another item of considerable interest, perhaps, is that about 95 per cent of the objects struck were wet at the time and rain was falling, leaving only about 5 per cent that were dry and struck when no rain was falling. In one case, the burning of a barn near Conneaut, Ashtabula County, March 26th, the report seems to indicate that snow was falling at the time of the stroke that caused the fire.

Another thing: The days on which thunderstorms are general over the State are relatively few. Of the 169 thunderstorm days in 1917, on 7 days only were thunderstorms general; on 11 days they covered about three-fourths of the State; on

23 days about one-half; on 17 days, nearly half the State; on the rest, they were local and limited.

As intimated above, the publication of this report (Thunderstorms in Ohio in 1917) has been and is being delayed on account of lack of the necessary funds.

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